AFOSR-TR- 82-0328

(12)

AD A113870

INVESTIGATIONS IN X-RADIATION STIMULATION

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MARCH 1982

Research Sponsored By The
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Under Grant AFOSR 76-3098

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFOSR-TR- 82-0328

2. GOVT ACCESSION NO.: AD-A113 874

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): INVESTIGATIONS IN X-RADIATION STIMULATION

5. TYPE OF REPORT & PERIOD COVERED: FINAL SCIENTIFIC REPORT 76 Sept 01 to 82 Jan 31

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): Kamalaksha Das Gupta

8. CONTRACT OR GRANT NUMBER(s): AFOSR [redacted]-76-3098

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Department of Physics and Engineering Physics
Texas Tech University
Lubbock, Texas 79409

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F 2301/B2

11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Office of Scientific Research (NE)
Bldg. 410
Bolling Air Force Base, D.C. 20332

12. REPORT DATE: Mar 1982

13. NUMBER OF PAGES: 54

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

CRYSTAL X-RAY LASER, COHERENT COLLECTIVE KOSSEL EMISSION FROM MONOCRYSTALS, DRIVING FREQUENCY, LASING FREQUENCY, LOSSY FACTORS, THRESHOLD PUMPING, NONDIVERGENT BORRMANN MODE, COUPLING OF BORRMANN, BRAGG, AND KOSSEL MODES.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective is to invent a crystal x-ray laser. The investigations in the Radiation Research Laboratory at Texas Tech University have established in a very straightforward way the line narrowing associated with a threshold pumping and a nonlinear rise in intensity. This work has attracted the attention of other world laboratories.

The recent work on x-ray Borrmann channeling via monocrystals has demonstrated the existence of a monochromatic x-ray beam without any vertical divergence. This would allow the transport of x-ray energy in space for thousands of miles --

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RESEARCH OBJECTIVES

The objective is to invent a crystal x-ray laser. A monocrystal as a source of coherent x-rays has been designated as a "crystal x-ray laser". The name is justified because an excited crystal generates a highly coherent beam of monochromatic x-rays with properties of line narrowing and a nonlinear rise in intensity with increase in the rate of pumping. The name "crystal x-ray laser" distinguishes and characterizes the source from any other source that generates x-ray laser without using a crystal. The existence of a crystal x-ray laser is proved beyond any doubt when a straightforward experiment demonstrates unambiguously an amplification of an x-ray signal passing through the excited crystal as a negative absorption.

The investigations[1,2,3] in the Radiation Research Laboratory at Texas Tech University, sponsored by the Electronic and Material Sciences Division of AFOSR, have established in a very straightforward way the line narrowing associated with a threshold pumping and a nonlinear rise in intensity. This work has attracted the attention of other laboratories of the world.[4,5] The results have established the existence of the stimulated x-ray emission from monocrystals. However, the observed stimulated coherent beam had a vertical divergence. The current experiment is to establish the amplification in a straightforward way introducing simultaneously the nondivergent property.

The recent work[6,7,8] on x-ray Borrmann channeling via monocrystals has demonstrated the existence of a monochromatic x-ray beam without any vertical divergence. This would allow the transport of x-ray energy in space for thousands of miles without any loss of power. Preliminary experiments with a monocrystal excited by pulsed x-rays at Air Force Weapons Laboratory, KAFB, Albuquerque, seem to indicate a gain in intensity of the nondivergent hot spot with a concomitant fading of the regular Laue pattern. Current investigations in this line indicates that with proper doping of the monocrystal the nondivergent beam could be increased in intensity using a flash x-ray tube to pump the doped monocrystal. A concial target double beam flash x-ray line source instrument has been constructed to obtain a beam of nondivergent, stimulated, coherent, monochromatic x-rays from doped monocrystals.

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MATTHEW J. KERPER
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An explanation as to the origin of the nondivergent x-ray beam in the light of recent understanding of the channeling of light via optical fibers as a soliton will be attempted.

The lifetime of x-ray excited states with K- hole is of the order of 10^{-15} seconds as determined by two crystal spectrometer and estimated theoretically by Lorentz. Such a short lifetime of the excited x-ray states necessitates an unusually high pumping rate to obtain a threshold for the required population inversion in an x-ray laser cavity. Our experimental results with $CuK\alpha_1$ radiation in polycrystalline copper crystal have demonstrated a 50 percent line narrowing of copper $K\alpha_1$ line, a nonlinear rise in intensity, and a threshold pumping rate with microfocus high density electron beam. This is attributable to very low lossy factors in a crystal cavity to be discussed later in detail. The objective in this project is to demonstrate the existence of an x-ray laser in a crystal cavity. Based on the experimental results and their analysis the crystals are classified into two broad categories: (a) crystals of low atomic number, Z less than 11, and (b) crystals of atomic number, Z greater than 10.

The experimental results with monocrystals and polycrystals at different pumping rates reveal interesting features of the nonlinear rise in intensity with increase in the rate of pumping. The existing coherent interactions of x-rays in periodic field of crystals are (a) Bragg and (b) Borrmann. The results of coherence and anomalous transmission of x-rays in these two processes have been classically explained by Ewald.[9] Experiments of Bragg resonance are done in two different modes. In reflection mode, the Bragg interference involves the crystal surface layer of micron order depth. In transmission mode, the radiation is channeled through lattice planes d_{hkl} at Bragg angle. Such channeling in thick crystals of high quality is the Borrmann mode that reveals unusually high penetrability of x-rays through monocrystals at proper channeling angles.

The investigations of stimulated x-ray emission from crystals have been done by exciting crystals to emit characteristic lines from the atoms of the crystal. These lines appeared as well known coherent Kossel cones from crystals due to an internal Bragg resonance. The interactions involved are named as Kossel-Bragg and Kossel-Borrmann.

In the case of Bragg and Borrmann an external collimated beam interacts with crystal planes at angles given by the Bragg law. The characteristic emission lines from crystal atoms generate interanl Bragg resonance modes and are emitted efficiently from the crystal edges as coherent Kossel lines. In stimulated x-ray generation an external collimated beam of frequency ν_D interacts with the crystal at Bragg angles as the driving frequency. The crystal is excited so that its atoms emit characteristic frequency ν_L of the same value of the driving frequency ν_D of the external collimated beam. The result is an interaction between the two Bragg resonance modes: the Kossel mode (internal) and the Bragg mode (external). The Kossel mode is a strictly standing mode with a long lifetime in the crystal. The Bragg mode due to an external collimated beam obey the momentum rules to be ejected from the crystal. If the pumping rate of the crystal supercedes the lossy factors, the driving frequency ν_D of the external collimated beam will induce emission from excited atoms of the crystal to the Kossel mode and the result is stimulated emission. Such a mechanism of stimulated Kossel due to an external Bragg as a driving frequency should increase the numerical value of the fluorescence yield $\omega_K = \frac{n_K - n_A}{n_K}$.

This means the manifestation of stimulated emission must accompany a decrease in the Auger cross section of the atoms in the crystal. The experimental results seem to indicate that the lifetime of a Kossel mode should be a function of the size of the crystal mosaic blocks or the size of the grains in a polycrystalline medium. The longer the lifetime of the Kossel mode the less strigent is the pumping rate.

The lossy factors are due to the competitive channels. In primary processes of interactions these are (i) photoelectric, (ii) Compton, (iii) thermal diffuse scattering close to the Bragg setting angle, and (iv) Compton-

Raman. The decay of a K- hole excited atom is associated with K- series emission lines and crystals with atomic number greater than 10, the L-, M-, etc. series lines follow. The noise that is introduced in the crystal due to the unwanted series lines of lower energy values does not allow a higher pumping rate of the crystal to continue with the nonlinear rise in intensity. A saturation ensues due to the noise generated in the crystal. The noise factor increases due to KLL, KLM, etc. and LMM, LMN, MNN, etc. Auger electrons interacting with atoms at the lattice sites. The unwanted Auger electrons ionize the crystal atoms and the number of the secondary electrons produced in the crystal increases with further increase in the number of Auger and photoelectrons. The cascade Auger process occurs contributing to the generation of electron-hole pairs in certain crystals.

The experiments have clearly revealed that the cross sections for the primary photoelectric and Compton processes at Bragg modes of the crystal are spectacularly reduced. The photoelectric and the Compton practically disappear at the Bragg resonance mode. The other advantageous factor is due to the fact that a Kα photon of an atom cannot be absorbed by a ground state atom. This is because the L- level is already occupied to its allowed number of electrons. For this reason alone, the lifetime of the Kα *Kossel mode* will be long enough in the crystal cavity.

The crystal impurities, dislocation, and surface irregularities reduce the lifetime of the Kossel mode. The leakage of the Kossel mode photons are from the crystal edges in Bragg-Borrmann-Kossel modes.

It has been determined that the population inversion is possible with crystals of atomic number less than Z=11, in compound crystals with allowed and forbidden electron states.

OBSERVATION OF NONLINEAR RISE IN INTENSITY FROM COPPER

EXPERIMENT: A demountable microfocus tube in which both the polycrystalline copper target and the electron gun filament can be changed conveniently has been used. The target can be rotated manually in vacuum in order to locate the best area of the target to obtain a miximum intensity of copper $K\alpha_1$ peak dispersed by the spherically bent crystal spectrometer for a fixed current density at the target. The electrical bias control on the electron gun changes the size of the focal line on the target. The sharper the line the higher the current density. In different sets of experiments the area of the target bombarded by electrons is approximately 100 μm x 30 μm. A pinhole camera determines the size of the fine focus line at the target for different values of the tube current. The current density at the target is determined for different values of the tube current. The change in the size of the line focus for different tube currents is within the limit of ± 2 percent. This justifies the plotting directly the tube current as against the peak intensity of $K\alpha_1$ of copper measured by a multichannel analyzer. The estimated current density at the target is 500 times greater than the current density in a conventional x-ray tube. The current density at the microfocus target lies between 6 to 60 ampere per sq cm for the tube current between 0.2 to 2 mA. As shown in Fig. 1, a spectacular increase in intensity of copper $K\alpha_1$ has been demonstrated when the tube current increased from 0.1 to 0.3 mA. In one set of experiments the tungsten filament electron gun has been replaced by an oxide coated nickel wire. The length of the filament is 8 mm and the diameter is 0.5 mm. Experiments have been performed at tube potentials from 10 to 18 kV and the tube current has been varied between 0.1 to 0.6 mA. The observed nonlinear rise in intensity is most prominent and reproducible at 13 kV operating potential with a tube current between 0.17 and 0.5 mA.

The line focus of 100 μm x 30 μm, or less, on the copper target is nearly vertical. A horizontal slit 6 mm x 1 mm is set close to the beryllium window of the x-ray tube. The silicon crystal spectrometer is placed at a distance of 20 cm from the target focal point. The take off angle of the target radiation is approximately 9°. A proportional counter with a thin beryllium window is placed at a distance of 40 cm from the silicon crystal.[10] The position of the silicon crystal spectrometer and the

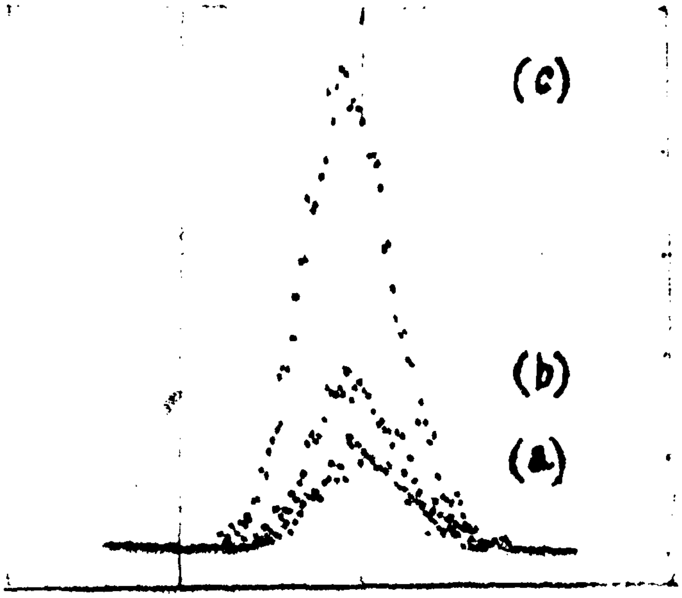

Figure 1. Multichannel analyzer display of copper $K\alpha_1$ emission line at 13 kV at different tube currents (a) 0.1 mA, (b) 0.2 mA and (c) 0.3 mA.

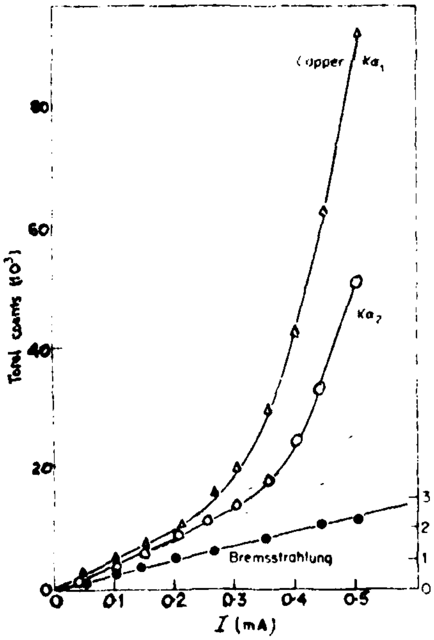

Figure 2. X-ray intensity versus microfocus tube current. The scale on the left side of the figure shows the total counts of $K\alpha$ lines for 100 s and the scale on the right side shows the total counts of bremsstrahlung for 100 s.

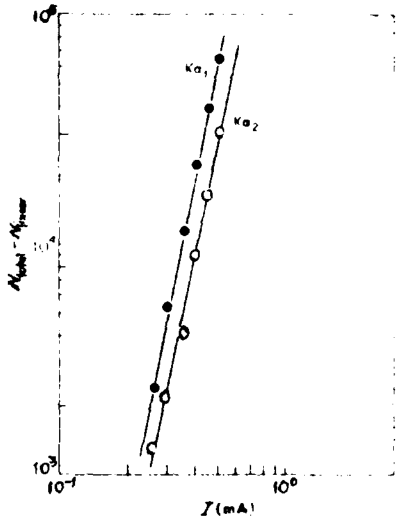

Figure 3. A log–log plot of N_{total} (experimental) – N_{linear} (extrapolated) versus tube current. The straight lines are least square fitting to the data.

Figures reprinted from: K. Das Gupta et al, X-Ray Spectroscopy 9, 25, (1980).

counter are adjusted to obtain the $CuK\alpha_1$ peak at 79.36° Bragg angle for fourth order reflection. A rectangular lead slit of 0.2 cm x 0.5 cm, which corresponds to 5 eV width in the fourth order of reflection, was positioned vertically at the counter to select either $K\alpha_1$, $K\alpha_2$, or the high energy bremsstrahlung. As can be seen from Fig. 2, the intensity of the $K\alpha_1$ peak is greater than the intensity of the bremsstrahlung by a factor of 37 at 0.5 mA.

The high resolving power of the silicon crystal in fourth order reflection together with a high dispersion in our experimental setup produce a $K\alpha_1$ to $K\alpha_2$ seperation at the counter position of 0.87 cm.

The data were collected with a multichannel analyzer (Tracor Northern Model NS-710) which provided both peak and integrated intensity. The integrated intensity was obtained by using a region of interest which covers the entire line profile as shown in Fig. 1. The same region of interest was used for collecting all data.

To collect the data for copper $K\alpha_2$ the counter with its attached collimator was moved to obtain the copper $K\alpha_2$ peak and the data were collected in the same manner as the copper $K\alpha_1$ line. The dead-time of the multichannel analyzer never exceeded 5% to ensure that the line position as a function of energy does not shift with change in count rate. To study the behavior of the bremsstrahlung at an energy greater than $CuK\alpha_1$, the counter was moved, accordingly, to a position to receive the high energy continuum part of the spectrum.

RESULTS: Copper $K\alpha_1$ and $K\alpha_2$ lines show nonlinearity between tube currents of 0.15-0.5 mA as shown in Fig. 2. Above 0.5 mA tube current the curve bends in the opposite direction. The results beyond the nonlinear range about 0.5 mA seem to be due to overheating and melting of the polycrystalline copper target surface caused by electron bombardment.

As can be seen from Fig. 2 at relatively low current, 0.05-0.15 mA, the behavior of the curve is linear. If this behavior continued at higher current an extended straight line would be obtained (see Fig. 2). It is well known that such a linear rise in intensity with tube current is the normal behavior of x-ray emission lines. In our analysis we have subtracted the points of the extended straight line from the corresponding points in the actual nonlinear curve. This difference for various points versus the tube current is presented in the log-log plot in Fig. 3. The log-log plot together with the straight line discussed above were used to obtain an empirical relation between the tube current and the total counts. This relation is of the general form†

$$N_{total} = N_{linear} + N_{nonlinear} = aI + bI^n \qquad (1)$$

where N_{total}, N_{linear}, and $N_{nonlinear}$ are the total, linear and nonlinear counts, respectively, I is the tube current in mA, and a, b, and n are constants. Respresentative values of these constants are given in Table I.

Table I. The calculated parameters of Eqn(1)[a]

	$K\alpha_1$	$K\alpha_2$	Bremsstrahlung
a (counts s^{-1} mA^{-1})	4.61×10^4	3.8×10^4	4.56×10^4
b (counts s^{-1} mA^{-n})	2.15×10^6	8.1×10^5	-
n	5.06	4.7	

[a]Tube potential = 13 kV; the target is polycrystalline copper; the target area is 100 μm x 30 μm; the multichannel collecting period is 100 s.

It is important to mention here as an experimental result that the parameter of Eqn (1) are dependent on the tube potential. On increasing

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†We have not used a relation of the form $N_{total} = A \exp(BI)$ (where A and B are constants, and I is the tube current) because our experimental results show that as the tube current goes to zero the total counts correspondingly goes to zero.

the tube potential the nonlinear part has been found to decrease gradually until the linear part is prominent.

DISCUSSION: Our systematic and repeated investigations have shown that the nonlinearity is most important for a tube potential of 13 kV and tube currents between 0.1 and 0.5 mA. We have also observed that the nonlinear behavior is most prominent only for certain areas of the target. This could be due to the orientation of the crystal grains of the copper target emitting the internally Bragg reflected Kossel lines of $CuK\alpha_1$ and $CuK\alpha_2$. For some other areas of the target we have observed a strictly linear relationship between the count number and the tube current. The observation of such nonlinearity is rather unusual in the field of x-rays and is one characteristic feature of the stimulated emission in the optical region. Therefore, we have concluded that the observed nonlinear rise in intensity could be due to the stimulated emission of x-rays.

THRESHOLD, LINE-NARROWING, AND A NONLINEAR RISE IN INTENSITY

HIGH RESOLUTION SPECTROSCOPY OF KOSSEL EMISSION FROM COPPER CRYSTAL: Copper $K\alpha_1$ and $K\alpha_2$ lines have been dispersed by a spherically bent mica crystal in 8th order of reflection to obtain high resolution.[11] The polycrystalline copper target is excited by high density electron beam in a microfocus x-ray tube. The surface erosion of the water cooled copper target starts beyond the tube current 1.2 mA. Systematic work has been done to determine the increase of the intensity of $K\alpha_1$ and $K\alpha_2$ of copper as the tube current is increased from .1 - 1.1 mA at 40 keV.

The experiments were conducted a number of times by changing the position of the copper target by rotating the target in vacuum to obtain a significant intensity corresponding to the position of the Kossel emission from (111) planes. In each of these different sets of experiments a nonlinear rise in intensity has been observed. In similar laboratory experiments a strictly linear intensity variation of the copper Kα lines with increasing tube current is observed when the maximum value of the current density at the target is of the order of 10 mA/cm^2, as in commercial x-ray tubes. In a microfocus tube, due to the high density electron beam, the target tends to melt at the focal point if the current density if increased beyond 4000 mA/cm^2. At this rate of pumping 50 copper Kα photons are generated at the crystal grains in 10^{-13} seconds, the lifetime of x-ray emission. The lifetime of x-ray states has been determined by a three crystal spectrometer.[12] The experimental work and theoretical analysis have been confirmed by Eisenberger et al.[13] At tube currents .1, .2, .5, .8, and 1.1 mA the full width at half maximum intensity of copper Kα_1 and Kα_2 at the eighth order of reflection obtain high resolution. A 50 percent line-narrowing for copper Kα_1 and a 40 percent narrowing for copper Kα_2 have been recorded. The ratio of the intensity of Kα_1 and Kα_2 peaks increased by 10 percent from 0.1 to 1.1 mA.

The fundamental width (FWHM) in eV has been plotted against the tube current in Fig. 4. The line width vs. current density at the target clearly reveal a threshold at about 0.3 mA tube current as shown in Fig. 4.

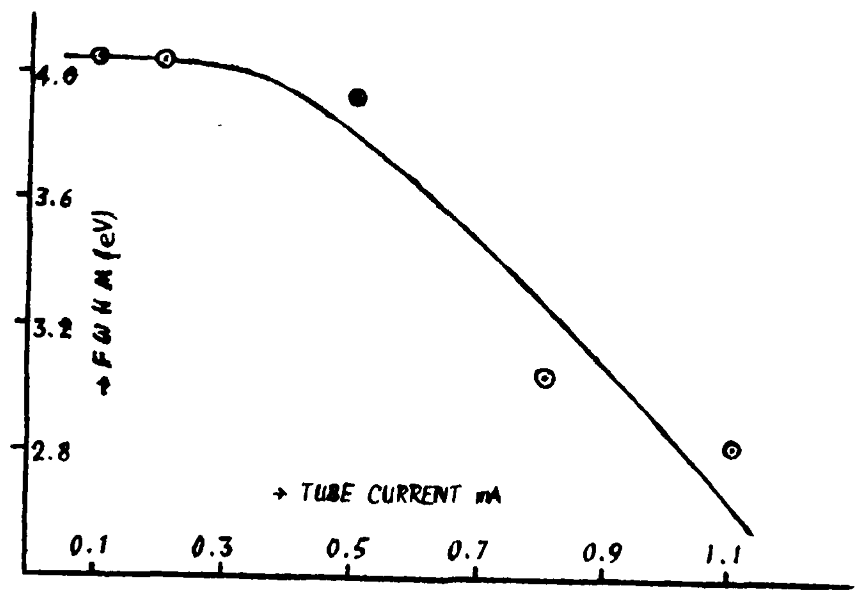

Fig. 4: Narrowing of Fundamental Width of Copper Kα_1 Line at High Current Density

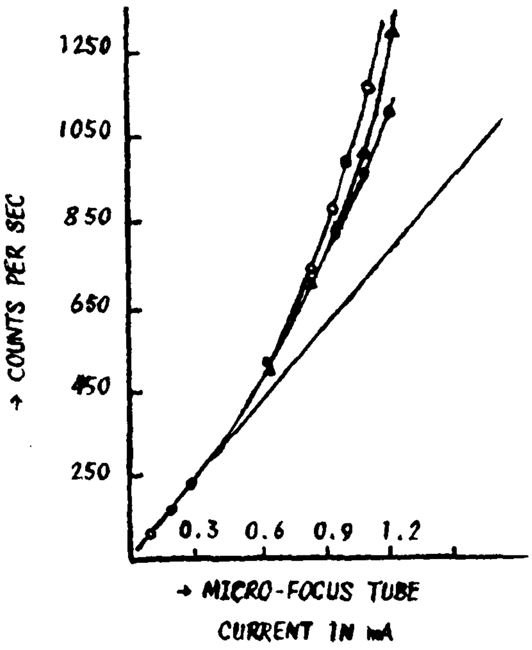

Fig. 5: A Nonlinear Rise in Intensity of Copper $K\alpha_1$ Peak

In these experiments the tube currents to excite atoms of copper crystal were continuous and surface erosion started at the microfocus beyond 1.2 mA. To study the nature of nonlinear rise in intensity and the associated line narrowing at higher current density and therefore higher pumping rate of the crystal, a pulsed electron beam is to be used with more efficient cooling of the target.

NONDIVERGENT MONOCHROMATIC X-RAY BEAMS FROM Ge AND GaAs MONOCRYSTALS

In the 1920's and 1930's a number of investigators proved conclusively that atoms at the lattice sites of monocrystals, excited in a typical case by ionization of the innermost K-shell, become a source of coherent monochromatic x-radiation. The characteristic x-ray line from the excited cones of monochromatic x-ray given by the relation $n\lambda = 2d \sin \Theta$. Such cones of x-rays leak through the surface edges of the crystal and appear as sharp lines on films as projections of Kossel cones. Such coherent x-ray lines from monocrystals are known as Kossel lines. In the 1950's Borrmann discovered that collimated monochromatic beam of x-rays can be channeled at Bragg angles via the lattice planes of nearly perfect thick crystals with strikingly low absorption. This is the Borrmann effect. The two major quantum interaction processes, the photoelectric and the Compton, almost disappear abruptly in a spectacular way as the monocrystal is rotated through the Bragg angle with respect to the collimated beam for Borrmann channeling. In understanding the Borrmann process, P.P. Ewald[9], who developed the dynamical theory of x-ray diffraction, remarked: "Apart from the remarkable fact that any x-radiation at all penetrates the crystal, the angular spread of each of the transmitted beams is surprisingly narrow, and they emerge on the exit side of the crystal at a point reached from the entrance slit by an apparant energy flow along the reflecting net planes". To understand the generation of the Bragg resonance modes in a crystal Ewald conceived of a self consistent system of resonator vibrations and emissions, so that one maintains the other, introducing the concept of dipole waves. Referring to the Borrmann channeling, Ewald remarked[9], "It is obvious that the energy flow takes place along the reflecting planes, since standing waves do not transport energy".

For a number of years, I have been looking for a combined effect of the Kossel and Borrmann. This is a study of collective emission process when atoms at the lattice sites of a monocrystal are the emitting sources in a Kossel process and are subject to the influence of an external collimated beam of the same frequency as the Borrmann channeling driving frequency. The coherent radiation thus obtained is designated as Kossel- Borrmann radiation. Using a copper target I have reported earlier[1,2] the results of high resolution spectroscopy of the $CuK\alpha_1$ and $K\alpha_2$ Kossel lines from copper crystal. I have observed and reported (a) a nonlinear rise in intensity, (b) a threshold pumping rate to obtain a line narrowing, and (c) more than 50 percent line narrowing. It is interesting to note that a group of theoretical physicists, Akhmanov and Grishanin of Moscow State University[4] and

Bertolotti and Sibilia of the University of Rome[5], also conceived of coherent emission from monocrystals and referred to our work on stimulated emission on x-rays from crystals.

In our experimental setup, to obtain a stimulated Kossel line from a crystal cavity, the pumping rate of the crystal is low enough to be attained using a microfocus electron beam to excite the copper crystal. This has been qualitatively attributed to the lifetime of the Kossel mode that is needed to stimulate the $K\alpha$ emission feeding into the Kossel mode. The lifetime of the Kossel mode depends on the size, shape, the specific lattice planes, and the degree of perfection of the monocrystal. In a typical case of generation of the $K\alpha_1$ line as a stimulated beam it is to be noted that the K- shell electron of a ground state atom cannot absorb the $K\alpha_1$ radiation of the same atom. In coherent Kossel emission from a monocrystal the lossy factor is significantly reduced due to this cause. This is a distinct advantage over an optical laser cavity. But $K\alpha_1$ radiation can be absorbed by L-, M-, etc. shell electrons that subsequently introduce a noise factor due to generation of L-, M- series lines. In problems of crystal x-ray laser, the unavoidable lossy factor, due to the fluorescence yield ω_K, will increase when stimulated emission starts. In my work on stimulated x-ray emission from crystals, I have so far failed to obtain a nondivergent beam as Kossel-Borrmann radiation.

In this report, I present the experimental evidence of the (a) generation of a nondivergent beam (NDB) of x-ray from monocrystals of germanium and gallium-arsenide without using any collimator, and (b) the pulse height spectra of the NDB when $AgK\alpha_1$ radiation is channeled via 440 planes of germanium.

EXPERIMENTAL METHODS TO OBTAIN NONDIVERGENT X-RAY BEAMS

METHOD I: BORRMANN CHANNELING OF A CONVERGENT BEAM: A line source of x-rays, 12.5 x 0.8 mm, from a sealed off silver target x-ray tube is positioned in a horizontal plane. A lead shutter with a pinhole, or a slit, is positioned vertically with respect to the horizontal line focus that emits x-ryas. For a typical setting, the Bragg angular range for a fixed vertical position of the Ge, or GaAs, 220 planes lie between 14 - 24°. This angular range channels any characteristic target line and the continuum via 220 planes in first and second order of Bragg in transmission. This will be refered to as the Borrmann channeling for thick crystals. For the angular range between 14 - 24° the wavelengths recorded are between 0.48 - 1.6 Å.

The horizontal surface plate fixed below the monocrystal is marked with a line perpendicular to the crystal surface and parallel to the 220 planes of the crystal. The size of the crystal is 10 x 6 x 0.5 mm. The surface is parallel to 111 planes and the 220 planes are perpendicular to the surface 111 planes. The surface plate is marked in degrees with a circular scale so that the direction of x-rays channeled at different Bragg angles can be located. $AgK\alpha_1$ line is channeled via 440 planes of Ge crystal at 16.24°. A copper tube, closed at the ends with thin mylar, is evacuated and positioned by optical laser alignment so that $AgK\alpha_1$ and $K\alpha_2$ x-rays from the Ge crystal travel up to 8 meters, the maximum distance to the laboratory wall. There is an arrangement to study photographically these lines up to a distance of 8 meters at interavals of 2 meters. The x-ray tube is run at various voltages of 30, 35, 40, 45, and 48 keV and the tube current is between 20 - 30 mA. The photographs in Fig. 6 are taken at distances of 4 and 8 meters with a Ge crystal at 45 keV and 20 mA with a two hour exposure. A xenon proportional counter is placed at a distance of 4 meters and with a calibrated multichannel analyzer the pulse height spectra of $AgK\alpha_1$ and $AgK\alpha_2$ are recorded, as shown in Fig. 7.

METHOD II: BORRMANN CHANNELING OF A COLLIMATED BEAM VIA 440 PLANES OF Ge CRYSTAL: A collimator is fixed to the x-ray tube to obtain a beam of x-rays having a horizontal divergence of 5 minutes of arc and a vertical divergence of 30 minutes of arc. A spectrometer is used to set the Ge monocrystal to obtain the Borrmann channeling via 440 planes of the crystal. The spectrum is recorded photograhically and the pulse height spectrum is

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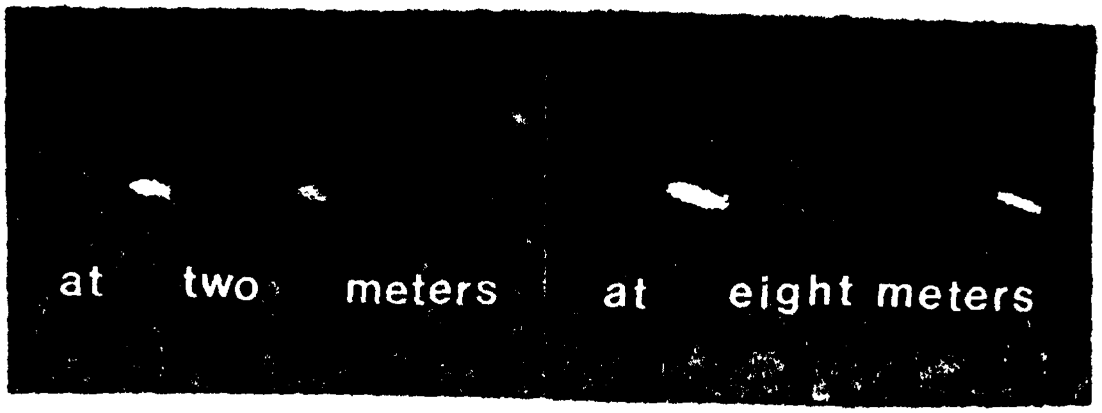


Fig. 6: Nondivergent Hot Spot Superposed on AgKα_1 and AgKα_2 Channeled Via 440 Planes of Ge.

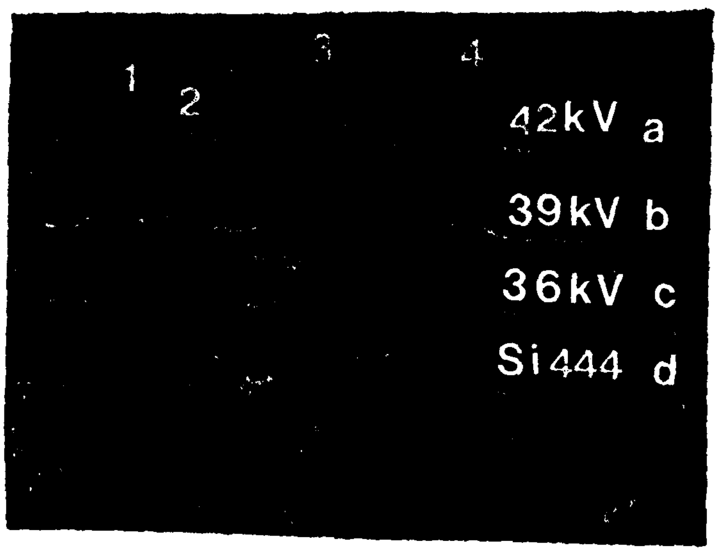


Fig. 7 (a), (b), (c): Pulse Height Spectra of the Hot Spot on AgKα_1 Line Taken at 4 m Distance from the Ge Crystal. The Bottom Curve is the Calibration Curve.

obtained by using the same detector system as described in Method I.

EXPERIMENTAL RESULTS: Adopting the experimental Method I, we have registered photographically Ag$K\alpha_1$, $K\alpha_2$, and $K\beta_1$ lines with superposed hot spots channeled via 440 planes of Ge crystal, see Fig. 6. A large number of such x-ray pictures, taken at different times with 10 different pieces of Borrmann quality Ge crystal, clearly reveals the existence of nondivergent x-ray beams that produce nondivergent hot spot superposed onto the characteristic Ag K- series lines. These characteristic lines appear precisely at calculated Bragg angles for Borrmann channeling via 440 planes. The vertical size of the hot spots are measured with a microcomparator for hot spots taken at 2, 4, 6, and 8 meters away from the crystal. The measment of the vertical size of the hot spot strikingly reveals that, within the limits of error in our experiments using the photographic technique, the vertical size does not change for different distances of the film from the crystal. The vertical size of the hot spots taken with holes in the lead shutter of different sizes, 1/16, 1/8, and 1/4", does not change the vertical size of the hot spot for a fixed width of the line focus at the target equal to 0.8 mm. This size of the hot spot for different distances of the film from the crystal is equal to the size of the vertical width of the line focus at the target for pinholes at the shutter larger than the width of the line focus. These experiments demonstrate that the vertical size of the hot spot is independent of the collimation of the incident beam that channels through the crystal. The incident beam, the normal to the 440 planes, and the nondivergent beam that produces the hot spot on the film always lie in one plane. In our experiments this is a horizontal plane.

The size of the nondivergent hot spot can be controlled to the size of the order of a micron by making a micron pinhole at the lead shutter when the vertical width of the line focus at the target is greater than or equal to a micron. In all these experiments for different distances of the film the vertical length of the silver K- series lines increase with film distance in accordance with the calcualted values of the vertical divergence for various sizes of the holes in the lead shutter. Similar results have been obtained with GaAs crystal.

We have taken the pulse height spectra of the hot spot superposed onto the $AgK\alpha_1$ line using a xenon proportional counter and a multichannel analyzer. The hot spot on $AgK\alpha_1$ line was isolated from the rest of the channeled spectra by using a copper tube collimator of 4 meters length. There are two slits of tantalum S_1 and S_2, each of horizontal width 1.5mm, fixed at the two ends of the 4 meter long copper tube collimator. The horizontal divergence angle is 1.3 minutes of arc which contributes to a spread of the $AgK\alpha_1$ line by $\Delta\lambda = \pm 0.0007$ Å centering the peak of $AgK\alpha_1$ line. We studied the radiation passing through the copper tube collimator scattered at an angle of 16.24° ± 0.021° from Ge crystal. At this angle we observed $AgK\alpha_1$ via 440 planes and could also record the continuum target radiation of wavelength 1.118 Å at 11.18 keV channeled via 220 planes of the Ge crystal. In Fig. 7, the bottom curve is the calibration curve obtained from 444 reflection of $AgK\alpha_1$ from a silicon crystal. The peaks 1, 2, and 3, in Fig. 7 calibration curve, correspond to energies 16.6, 22.2, and 27.7 keV. The pulse height spectra of the hot spot superposed onto $AgK\alpha_1$ line when the x-ray tube is operated at 42, 39, and 36 keV at 20 mA are shown in Fig. 7 (a), (b), and (c) respectively. The peaks 1, 2, 3, and 4 are energies 11.1, 15.0, 22.0 and 28.0 keV respectively with an error of ± 1 keV. The peak 1 corresponds to the channeled continuum target radiation via 220 planes of Ge at an angle of 16.26° and the peak 3 is $AgK\alpha_1$ channeled via 440 planes. The peaks 2 and 4 remain unexplained until futher investigation.

DISCUSSION: More or less similar looking hot spot were observed in Ge crystal by Borrmann and Hartwig.[14] They observed that 111 reflection through Ge crystal undergoes additional enhancement when the $11\bar{1}$ reflection is simultaneously in diffraction position. In our experimental setup with a collimated $AgK\alpha_1$ radiation striking 440 planes of a germanium crystal at 16.24° the hot spot is generated superposed onto the 440 transmitted beam. Preliminary results, with a microsecond pulsed beam of Ag target radiation at 70 keV at 39 amp, generated a hot spot via 440 planes of a Ge crystal with a collimated beam striking the crystal at 16.24°. The hot spot was observed on a film with 50 pulses of x-rays each of 30 microseconds duration.

Experiments are in progress with Ge monocrystals doped with Ag atoms and pumped by an intense source of pulsed Ag target radiation excited by a high density electron beam from a Febetron accelerator.

ACCOMPLISHMENTS

1. With a high resolution three-crystal spectrometer[12] the lifetime of x-ray excited states has been determined. Our results and conclusions were verified by Eisenberger, Alexandropoulos, and Platzman at Bell Labs[13]. The lifetime is not 10^{-15} seconds as in the accepted literature, but it is 10^{-14} seconds or longer.

2. We observed a nonlinear rise in intensity of copper $K\alpha_1$ and $K\alpha_2$ lines with associated line narrowing of about 50 percent. The work attracted the attention of Akhmanov and Grishanin[4] and Bertolotti and Sibilia[5].

3. With a novel high resolution x-ray spectrometer[10], designed by Das Gupta, a functional relationship between the intensity of $CuK\alpha_1$ line and the tube current has been obtained.

4. A germanium monocrystal doped with copper revealed a nonlinear rise in intensity of $CuK\alpha_1$ from germanium crystal.[15]

5. A nondivergent x-ray beam has been produced by channeling $AgK\alpha$ and $MoK\alpha$ radiation via 440 planes of monocrystals of germanium and gallium-arsenide.[6,7,8]

6. A collimated x-ray beam from a silver target bombarded by electrons from a 70 kV, 3 amp pulsed power source[16] revealed the nondivergent x-ray beam channeled via 440 planes of germanium monocrystal.[8]

RESEARCH IN PROGRESS

1. Derived an equation that determines the characteristic frequencies of the incident x-ray beam to obtain a stimultaneous resonance of the forward Compton electrons and the backward Compton photons in a monocrystal. The wavelength of the backward Compton photon is an integral multiple of the de Broglie wavelength of the forward Compton electrons.

   The double beam Compton resonance experiment is in progress.

2. Using the thin film evaporation unit and the temperature controlled furnace, the method of doping by diffusion of the monocrystals of LiF, mica, Ge, Si, Cu, and calcium titanate has been developed in the material preparation section of the laboratory.

3. Compound crystals of Am Bn type have been selected such that the Auger electron of the low Z atomic number of element A have the same energy as the characteristic x-ray line from the element B. Also the momentum of the Auger electron of the element A is an integral multiple of the momentum of the characteristic photon from the element A. These experiments depend on the quality of the material preparation.

4. The construction of a conical double beam target for high intensity flash x-ray tube to have a simultaneous channeling through a monocrystal has been completed. The monocrystal doping is in progress.

5. A high resolution x-ray spectrometer has been constructed to be used to study the coherence and the nonlinear increase in intensity of the x-rays emitted from the output modulator in a 10 kV pulsed power klystron using monocrystals at the exit end of the klystron tube.

DESIGN AND CONSTRUCTION OF NOVEL X-RAY INSTRUMENTS IN THIS PROJECT

1. A high resolution 3-crystal spectrometer to measure the fundamental width, thermal diffuse scattering of x-ray lines, and the degree of perfection of the crystals.

2. Alignment of the microfocus target and the spherically bent crystal spectrometer in a Rowland circle to study the nonlinear effects in x-ray emission.

3. Microfocus x-ray diffractometer for precision measurement of thermal expansion coefficients of different sets of lattice planes of crystals.

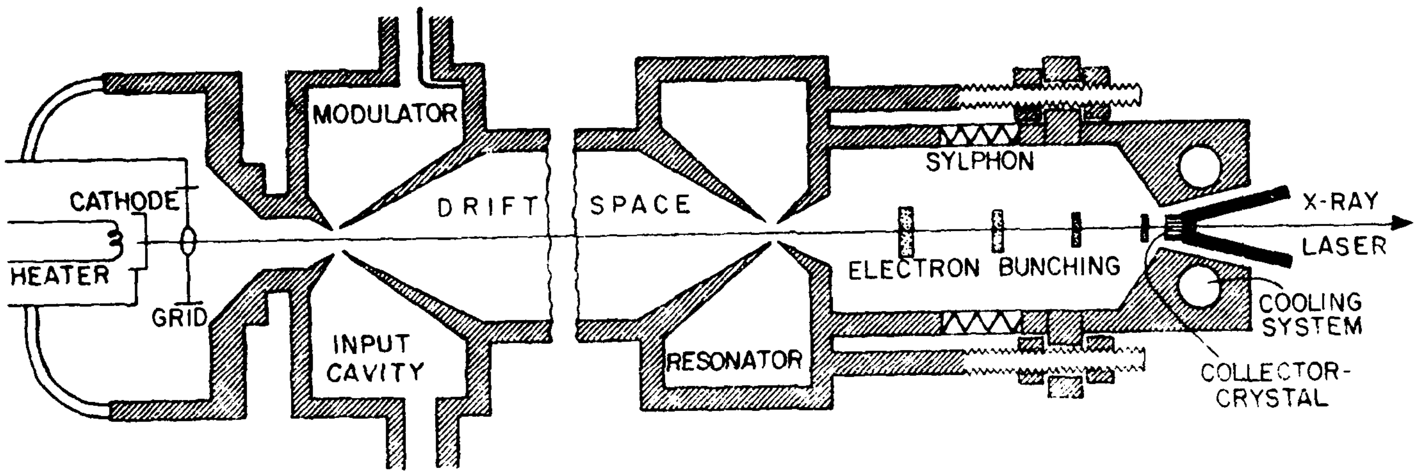
4. The Bragg-Borrmann channeling of monochromatic x-ray through crystals excited by electrons to generate the characteristic Kossel mode.

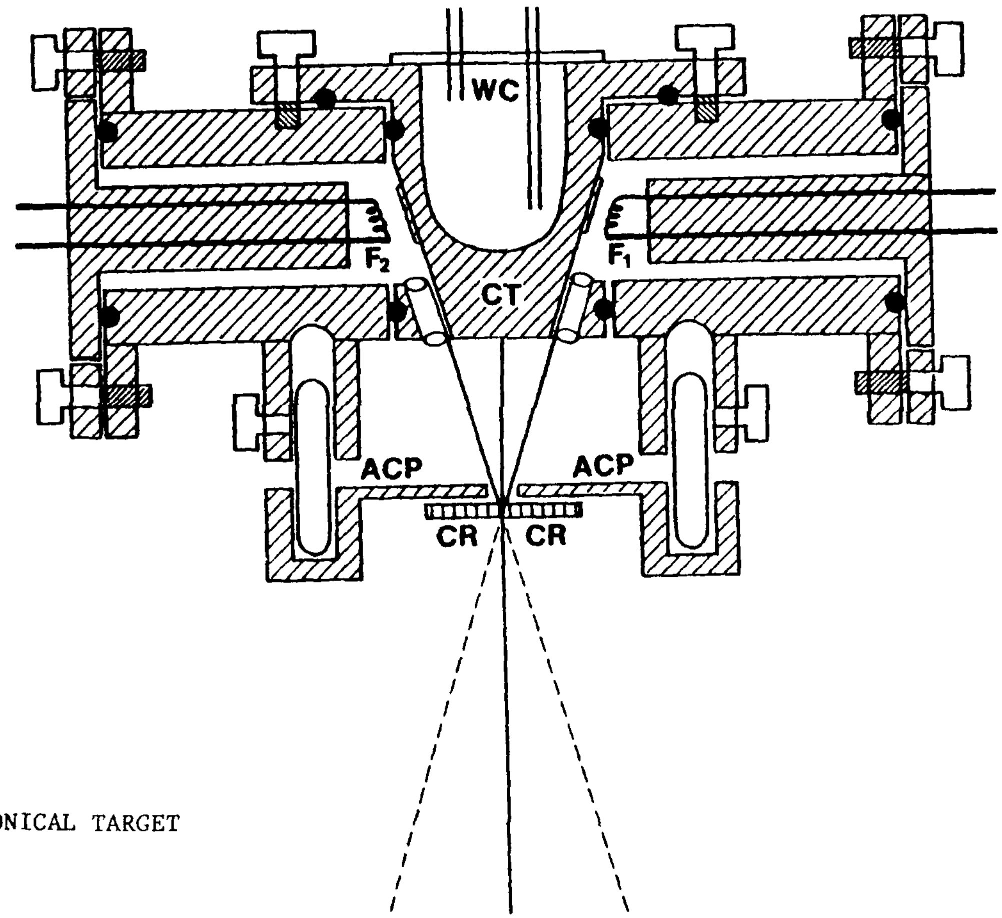
5. Bragg channeling of double x-ray beam from either side of the crystal plane via copper monocrystal excited by electron to generate the Kossel mode.

6. Nondivergent coherent x-ray beam through a 4m long vacuum pipe line in Borrmann channeling via Ge and GaAs monocrystal planes.

7. Conical target double beam flash x-ray tube for stimulated nondivergent hot spot.

PULSED X-RAY LASER USING BUNCHED ELECTRONS OF KLYSTRON (CONCEPT)





October 1981

MICROFOCUS E-BEAM ON CONICAL TARGET

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Department of Physics and Engineering Physics
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Lubbock, Texas 79409

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[14]G. Borrmann and W. Hartwig, Z. Kristallogr. 121, 401 (1965).

[15]K. Das Gupta and Peter J. Seibt, Twenty-Sixth Annual Conference on Applications of X-Ray Analysis, University of Denver, Denver, Colorado 104 (1977).

[16]K. Das Gupta and J. O'Loughlin observed the nondivergent hot spot from a germanium crystal using the pulsed power source at Air Force Weapons Laboratory, KAFB, December 1981.

ATTACHMENTS

I. AFOSR SUPPORTED PUBLICATIONS

II. AFOSR SUPPORTED PERSONNEL

III. AFOSR SUPPORTED GRADUATE STUDENTS

IV. PRINCIPAL INVESTIGATOR ORAL PRESENTATIONS

V. PRINCIPAL INVESTIGATOR RESUME

VI. PRINCIPAL INVESTIGATOR COMPLETE PUBLICATION LIST

LIST OF PUBLICATIONS RESULTING FROM AFOSR SUPPORT TO PRINCIPAL INVESTIGATOR

K. Das Gupta
1967-Present

COMPTON RAMAN SCATTERING IN X-RAYS
K. Das Gupta
XII Colloquium Spectroscopicum, Internationale, Ottawa, 413 (1967).

RADIATION AND SOLID STATE RESEARCH
K. Das Gupta
Dept. of Physics, Texas Tech University, (1968).

COHERENT CRYSTAL RADIATION AFFECTS THE MEASUREMENT OF THE X-RAY LINEWIDTHS
K. Das Gupta and Herbert Welch
Phys. Rev. Letters 21, 657 (1968).

OBSERVATION OF FINE STRUCTURES OF CHROMIUM $K\alpha_{1,2}$ LINES WITH A HIGH RESOLUTION THREE CRYSTAL SPECTROMETER
M. Shah and K. Das Gupta
Physics Letters 29A, 570 (1969).

MODIFIED X-RAY SCATTERING CLOSE TO THE BRAGG SPECTRUM
K. Das Gupta
International Symposium Kiev, 193 (1969).

OBSERVATIONS OF STRUCTURES IN THE CHROMIUM $K\alpha_1$ LINE WITH SPHERICALLY BENT CRYSTAL SPECTROMETER
K. Das Gupta and P.F. Gott
Physics Letters 33A, 276 (1970).

RADIATION LABORATORY FOR BASIC APPLIED RESEARCH
K. Das Gupta
Dept. of Physics, Texas Tech University, (1971).

COHERENT INTERACTIONS OF PHOTONS AND ELECTRONS IN CRYSTALS CLOSE TO THE BRAGG ANGLE
K. Das Gupta
Journal De Physique 32, C4-338 (1971).

SOME NEW METHODS OF PRECISION X-RAY SPECTROMETRY
K. Das Gupta, P.F. Gott, Herbert Welch, John F. Priest, Sunny Cheng, and Edmound Chu
Advances in X-Ray Analysis 16, 251 (1972).

EVIDENCE OF STIMULATION IN X-RAY EMISSION
K. Das Gupta
Colloquium Spectroscopicum Internationale XVII, ACTA II, 482 (1973).

NON-LINEAR INCREASE IN BRAGG PEAK AND NARROWING OF X-RAY LINES
K. Das Gupta
Physics Letters 46A, 179 (1973).

OBSERVATION OF COHERENT CHARACTERISTIC FREQUENCIES IN BREMSSTRAHLUNG
K. Das Gupta
IEEE Journal of Quantum Electronics QE-10, 778 (1974).

OBSERVATION OF FINE STRUCTURES IN $K\alpha_1$ LINES OF 3d TRANSITION ELEMENTS USING A THREE CRYSTAL SPECTROMETER
S.M. Shah and K. Das Gupta
J. Phys. Soc. Japan 37, 1069 (1974).

RADIATION LABORATORY BASIC APPLIED RESEARCH
K. Das Gupta
Dept. of Physics, Texas Tech University, (1974).

A HIGH RESOLUTION THREE CRYSTAL SPECTROMETER FOR THE USE IN X-RAY EMISSION SPECTROSCOPY
S.M. Shah and K. Das Gupta
Japanese Journal of Applied Physics 13, 2042 (1974).

NONDIVERGENT RADIATION OF DISCRETE FREQUENCIES IN CONTINUOUS X-RAY SPECTRUM
K. Das Gupta
Phys. Rev. Letters 33, 1415 (1974).

DIFFRACTION OF DISCRETE X-RAY FREQUENCIES FROM GERMANIUM ATOMS IN CRYSTALS
K. Das Gupta
J. Appl. Phys. 47, 2765 (1976).

A NEW TYPE OF KOSSEL-BORRMANN RADIATION FROM GERMANIUM CRYSTAL
K. Das Gupta
International Conference on the Physics of X-Ray Spectra, Gaithersburg, Md., 260 (1976).

A NONLINEAR RISE OF CHARACTERICTIC X-RAYS FROM GERMANIUM CRYSTAL
K. Das Gupta and Peter J. Seibt
Twenty-Sixth Annual Conference on Applications of X-Ray Analysis Abstracts, University of Denver, Denver, Colorado, 104 (1977).

GENERATION OF X-RADIATION Via ELECTRONS IN A CRYSTAL: NON-LINEAR RISE AND LINE-NARROWING
K. Das Gupta
PHYSICS OF QUANTUM ELECTRONICS VOL. 5 NOVEL SOURCES OF COHERENT RADIATION, S.F. Jacobs, M. Sargent III, and M.O. Scully, (Addison Wesley Publishing Co, Inc. Reading, Mass., 1978) p.381-398.

STUDIES OF THE NONLINEAR RISE IN INTENSITY OF X-RAY LINES
K. Das Gupta, A.A. Bahgat, and Peter J. Seibt
X-Ray Spectroscopy 9, 25 (1980).

OBSERVATION OF AN X-RAY BEAM OF 10 MICRORADIAN DIVERGENCE WITHOUT USING ANY COLLIMATOR
K. Das Gupta
To Appear in ADVANCES IN X-RAY ANALYSIS, Vol. 25, 1982, by Plenum Publishing Corp., New York.

NONDIVERGENT MONOCHROMATIC X-RAY BEAMS FROM Ge and GaAs MONOCRYSTALS
K. Das Gupta
To Appear in Lasers '81 Conference Proceedings by Society for Optical and Quantum Electronics, McLean, Virginia, 1982.

PERSONNEL September 1976 to January 1982

The following is a list of all personnel supported in whole or part with AFOSR Grant 76-3098 Funds or Equipment or by matching funds from Texas Tech University.

*Indicates persons working at end of Report Period: January 1982.

<u>September 1976 to September 1977</u>

Principal Investigator
*K. Das Gupta — September 1976-continued.....

Senior Technician
*Bob L. Burch — September 1976-continued.....

Office and Lab Attendant
*Aleeta Sue Cooper — September 1976-continued.....

Research Scientist
Peter J. Seibt — September 1976-continued.....

Undergraduate Research Assistants
James Albone — September 1976-May 1977
Kim Shinn — September 1976-May 1977
James White — September 1976-May 1977

<u>October 1977 to September 1978</u>

Principal Investigator
*K. Das Gupta — .....October 1977-continued.....

Senior Technician
*Bob L. Burch — .....October 1977-continued.....

Office and Lab Attendant
*Aleeta Sue Cooper — .....October 1977-continued.....

Research Associate
Preston Gott — July 1978-August 1978

Research Scientist/Post-Doctoral Fellow
Peter J. Seibt — .....October 1977-continued.....
Sheldon S. Wald — October 1977-May 1978

Undergraduate Research Assistants
Olarn Boontheekul — October 1977-continued.....
Michael Alley — October 1977-continued..... [Jan-Aug'78 no funds]
Dwayne Weaver — October 1977-December 1977
Kevin Burkhard — January 1978-continued.....
Paul Dellenback — January 1978-May 1978
Jeff Valder — January 1978-May 1978

Personnel cont.

October 1978-September 1979

Principal Investigator
*K. Das Gupta .....October 1978-continued.....

Senior Technician
*Bob L. Burch .....October 1978-continued.....

Office and Lab Attendant
*Aleeta Sue Cooper .....October 1978-continued.....

Research Associate
Preston Gott July 1978-August 1978

Research Scientist
Peter J. Seibt .....October 1978-August 1979

Technician
Olarn Boontheekul September 1979-continued.....

Undergraduate Research Assistants
Olarn Boontheekul .....October 1978-January 1979
Michael Alley .....October 1978-December 1978
Kevin Burkhard .....October 1978-continued.....
Christopher Yimbo May 1979-July 1979
Gabriel Umerah May 1979-continued.....
Isam Ayoubi June 1979-continued.....

October 1979-September 1980

Principal Investigator
*K. Das Gupta .....October 1979-continued.....

Senior Technician
*Bob L. Burch .....October 1979-continued.....

Office and Lab Attendant
*Aleeta Sue Cooper .....October 1979-continued.....

Research Associate
Preston Gott July 1980-August 1980

Technician
Olarn Boontheekul .....October 1979-May 1980

[continued]

Personnel cont.

October 1979-September 1980 cont.

Undergraduate Research Assistants

Kevin Burkhard	.....October 1979-May 1980
Gabriel Umerah	.....October 1979-January 1980
Isam Ayoubi	.....October 1979-August 1980
Daniel Alcorn	October 1979-May 1980 September 1980-continued.....
Kent Harlan	February 1980-May 1980
Mark Lotspeich	May 1980-continued.....

<u>October 1980-January 1982</u>

Principal Investigator

*K. Das Gupta	.....October 1980-present.....

Technician

*Bob L. Burch	.....October 1980-present.....

Office and Lab Attendant

*Aleeta Sue Cooper	.....October 1980-present.....

Undergraduate Research Assistants

James Albone	September 1981-December 1981
Mark Lotspeich	.....October 1980-August 1981
John Hurt	February 1981-May 1981
Eric Nelson	January 1981-May 1981
M. SanaTgar	February 1981-May 1981
Glenn Wade	November 1980-December 1980
Daniel Alcorn	.....October 1980-November 1980

PERSONNEL
RELATED PROJECTS

September 1976-January 1982

Listed below are those persons working in RELATED PROJECTS within the Radiation Research Laboratory but not supported by AFOSR Funds.

*Indicates persons working at end of Report Period: January 1982.

Post-Doctoral Research Fellow or Research Scientist	
*Peter J. Seibt	September 1979-present.....
A.N. Vishoi	June 1980-August 1981
A.A. Bahgat	January 1978-August 1979
Sheldon S. Wald	June 1977-September 1977
	June 1976-August 1976
Graduate Research Assistants	
*Timothy W. Henry	September 1981-present.....
Shih King Cheng	September 1976-May 1980
Amy Fung Lin Tung	September 1976-August 1977
Undergraduate Research Assistants	
*Mark Lotspeich	September 1981-present.....
*John Hurt	July 1981-present.....
Isam Ayoubi	September 1980-May 1981
	February 1979-April 1979
Gabriel Umerah	February 1980-May 1980
	February 1979-April 1979
Dwayne Weaver	June 1977-August 1977
James White	June 1977-August 1977
Olarn Boontheekul	September 1976-May 1977
Joe Dannemiller	September 1976-December 1976

DISSERTATION AND THESIS K. Das Gupta, Director

The following is a list of dissertations and thesis supported by past and present AFOSR Grant Funds and Equipment.

Herbert Eugene Welch
M.S. 1968
Precision X-Ray Spectroscopy with a Three Crystal Spectrometer

Herbert Eugene Welch
Ph.D. 1969
X-Ray Line Width Measurements with A Three-Crystal Spectrometer

Cecil Alan McClure
M.S. 1970
A New Method of X-Ray Spectroscopy Using Two Curved Crystals

Saiyed Masroor Shah
Ph.D. 1970
Observation of Fine Structures in the K-Alpha X-Ray Lines of Chromium and Cobalt

Bobby Bain Faulkner
M.S. 1971
Soft X-Ray Band Structures of Metals Using A Spherically Ben-Crystal Spectrometer

Robert Mays, Jr.
M.S. 1971
Determination of Refractive Indices for Various Solids by the Method of Total Reflection of X-Rays

John Priest
M.S. 1971
Observation of Fine Structures of X-Ray Lines in Some Transition Elements

Bruce H. Armstrong
M.S. 1972
Precision X-Ray Spectrometry at Low Temperatures

Hua May Lin Chen
M.S. 1972
X-Ray Study of the Transition of Amorphous Ni_{63}-Pd_{17}-Pd_{20} Alloy to a Crystalline State

Shih King Cheng (Sunny)
M.S. 1972
Precision X-Ray Spectroscopy in High Orders of Reflection

DISSERTATION AND THESIS continued

K. Das Gupta, Director

Franklin Potter
Ph.D. 1973
Soft X-Ray Spectra of Aluminum in Aluminum Nickel Alloys

Amy F. Lin
M.S. 1974
Anomalous X-Ray Diffraction at Small Angles

Taiann Hwa
M.S. 1975
Study of Borrmann Effect in Silicon Crystals

Cheng, Shih King (Sunny)
Ph.D. 1980
Study of Metal Films by the Method of Total Reflection of X-Rays

ORAL PRESENTATIONS

Invited Lectures and/or Papers Presented K. Das Gupta

1976

Special Conference: Los Alamos Scientific Laboratory, Laser Division, Los Alamos, New Mexico of the University of California, April 1976; "A New Type of Kossel Lines from Germanium Crystal".

Seminar: Department of Electrical Engineering, Texas A & M University, College Station, Texas, June 1976; "Nondivergent X-Rays with Van de Graaff Accelerator".

Presented Paper: International Conference on the Physics of X-Ray Spectra National Bureau of Standards, Gaithersburg, Maryland, August-September 1976; "Diffraction of Discrete X-Ray Frequencies from Germanium Atoms in Crystal". Abstract Published: Program and Extended Abstract: p. 260-261.

1977

Invited Lecture: 7th Winter Colloquium on Quantum Electronics, Park City, Utah, February 1977; "Generation of Simulated X-Rays from Crystal Cavity".

Seminar: Department of Physics, East Texas State University, Commerce, Texas, March 1977; "Coherent Interactions of Electrons and Photons in Crystals with Special Reference to X-Ray Laser".

Seminar: Department of Physics, Texas Christian University, Ft. Worth, Texas, March 1977; "Coherent Interactions of Electrons and Photons in Crystals with Special Reference to X-Ray Laser".

Presented Paper: 26th Annual Conference on the Applications of X-Ray Analysis: Denver, Colorado, August 1977; "A Nonlinear Rise of Characteristic X-Rays from Germanium Crystals". Abstract Published: Program and Abstracts, p. 104-105.

Invited Paper: The Physics of Quantum Electronics Conference, Telluride, Colorado, August 1977; "Generation of X-Radiation Via Electrons in a Crystal: Nonlinear Rise and Line-Narrowing". Paper Published In: PHYSICS OF QUANTUM ELECTRONICS Vol. 5: NOVEL SOURCES OF COHERENT RADIATION, Eds. S.F. Jacobs et al. (Addison-Wesley Publishing Co., Inc. Reading, Massachusetts, 1978) p. 381-398.

Special Invited Seminar: Jones Fellowships, College of Education, Texas Tech University, October 1977; "Applying Philosophy of Science to Educating Technique".

Seminar: Department of Physics, University of Texas at Austin, Austin, Texas, October 1977: "Progress Towards X-Ray Lasers".

ORAL PRESENTATIONS

Invited Lectures and/or Papers Presented K. Das Gupta

1978

Physics Colloquium: Department of Physics, Texas Tech University, February 9, 1978; "Stimulated Emission from Crystals".

Physics Seminar: Department of Physics, University of Texas at El Paso, February 20, 1978; "Stimulated Emission from Crystals".

Presented Paper: American Crystallographic Association Meeting, University of Oklahoma, Norman, Oklahoms, March 23, 1978; "High-Intensity of Pseudo-Kossel-Borrmann Pattern of Copper Through Activated Germanium Crsytal". Abstract Published: Program and Abstract. No. P8, p. 35.

Seminar: Institute of Optics, University of Rochester, Rochester, New York, March 27, 1978; "Stimulated Emission from Crystals".

Invited Lectures: Lawrence Livermore Laboratory, Livermore, California, June 27 and July 5, 1978; "Crystal X-Ray Laser, Part I and Part II".

Seminar: Electrical Engineering Department, Stanford University, Stanford, California, September 27, 1978; "Crystal X-Ray Laser".

Invited Lecture: Naval Research Laboratory, Radiation Technology Division and Optical Sciences Division, Washington, D.C. October 12, 1978: "Coherent Interactions of Electrons and Photons in Crystals: Crystal X-Ray Laser".

1979

Colloquium: Department of Applied Sciences, California Institute of Technology, Pasadena, California, January 3, 1979; "Observation of Stimulated Emission from Single Crystals in 1-2 Å Region".

Special Invited Seminar: Jones Fellowships, College of Education, Texas Tech University, Lubbock, Texas, February 22, 1979; "Applying Philosophy of Science to Education Technique".

Colloquium: Sandia Laboratory, Albuquerque, New Mexico, May 18, 1979; "Studies of the Nonlinear Rise in Intensity of X-Ray Lines".

Colloquium: University of Arizona, Tucson, Arizona, Department of Physics and Optical Science Center, May 21, 1979; "Coherent Interaction of Electrons and Photons in Crystals".

Paper Presented by Co-Author: Twenty-Eighth Annual Conference on the Application of X-Ray Analysis, Denver, Colorado, August 1, 1979; "X-Ray Study of the Band Structure in Stannic Oxide". Abstract Published: 1979, Program and Abstracts p. 23-24. Article Published: A.A. Bahgat and K. Das Gupta in ADVANCES IN X-RAY ANALYSIS, Vol. 23, Eds. J.R Rhodes et al. Plenum Publishing Corp. New York, N.Y. 1980) p. 203-207.

ORAL PRESENTATIONS

Invited Lectures and/or Papers Presented K. Das Gupta

1980

Invited Lecture: Varian Associates, Palo Alto, California, January 6, 1980; "Pulsed X-Ray Laser Using High Power Klystron".

Invited Lecture: Quantum Physics Group, University of Arizona, Tucson, Arizona, March 17, 1980; "Stimulated X-Radiation".

Invited Lecture: Stanford Synchrontron Radiation Laboratory, Stanford, California, June 6, 1980; "Soft X-Ray Laser (5-100 Å)".

Group Lecture: Department of Applied Science, California Institute of Technology, Pasadena, California, June 15, 1980; "Soft X-Ray Laser (5-100 Å)".

Informal Lecture to Selected Group; Department of Physics and Department of Applied Physics, Stanford University, Stanford, California, August 26, 1980; "Characteristic Peaks in Bremsstrahlung".

Presented Paper: Fifth International Conference on Small Angle Scattering SMAS, Berlin (West) Germany, October 6, 1980; "Study of Small Angle Scattering Using Two Curved Crystals in Cauchois Geometry". Abstract Published; Program and Abstracts. No. P15, p. 50.

Lecture Tour: October 1980: University of Munich and the Max Plack Institute for Plasma and Laser Physics in Munich, Germany; University of Paris; University of Manchester, England; "Current Research Findings on Crystal X-Ray Laser"; and University of Rome, Italy, "Observation of Characteristic Peaks in Bremsstrahlung".

ORAL PRESENTATIONS

Invited Lectures and/or Papers K. Das Gupta

1981

Informal Lecture to Selected Group: Air Force Weapons Laboratory, Kirtland Air Force Base, Albuquerque, New Mexico, March 11, 1981: "Using Pulsed Electron Beam to Obtain Coherent Stimulated X-Ray Emission".

Invited Lecture: Department of Physics, University of Texas at Austin, March 19, 1981; "Generation of Stimulated Emission from Germanium Crystals".

Invited Lecture: Sponsored Jointly by University of New Mexico, Optical Division of the Physics Department and Air Force Weapons Laboratory, Kirtland Air Force Base, Albuquerque, New Mexico, Given at AFWL/KAFB, May 27, 1981; "Nondivergent X-Rays from Ge and Ga-As Monocrystals".

Invited Lecture: Lawrence Livermore National Laboratory, June 24, 1981; "Observation of Nondivergent X-Ray Beams from Germanium Monocrystals".

Presented Paper: 30th Annual Conference on the Application of X-Ray Analysis: Denver, Colorado, August 5, 1981; "Observation of an X-Ray Beam of 10 Micro-radian Divergence Without Using Any Collimator". Accepted for Publication in ADVANCES IN X-RAY ANALYSIS, Vol. 25, 1982, by Plenum Publishing Co. New York.

Invited Paper: Intenational Conference: Lasers '81, New Orleans, LA., December 15, 1981; "Nondivergent Monochromatic X-Ray Beams from Ge and GaAS Monocrystals". Accepted for Publication in the Conference Proceedings by the Society for Optical & Quantum Electronics, McLean, Virginia, 1982.

RESUME

KAMALAKSHA DAS GUPTA

PII Redacted [redacted] [redacted]

[redacted] [redacted] [redacted]

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Education:

High School: New India High School, Calcutta, India; Graduated 1932

Degrees: B.S. 1937; Calcutta University, Physics-Honours Distinction

M.S. 1940; Calcutta University, Physics-Honours Distinction

Ph.D. 1952; University of Liverpool, England, Physics-Problems of Soft X-Ray Spectroscopy of the Solid State: under the direction of the Late Professor H.W.B. Skinner, F.R.S.

Professional Record:

A. Permanent

1940-47 First Research Fellow and Senior Lecturer, Scottish Church College, Calcutta University, Calcutta, India.

1948-50 Research Fellow, Gov. of India, National Institute of Sciences, Calcutta University, Calcutta, India; under the direction of Professor S.N. Bose, F.R.S.

1953-56 Assistant Professor, Graduate School, University of Calcutta, Calcutta, India

1959-61 Reader (Associate Professor) in Physics, in Charge of the Radiation Laboratory, Calcutta University, Calcutta, India

1961-66 Senior Research Fellow (Associate Professor Rank) Materials Sciences Department, California Institute of Technology, Pasadena, California

1966-present Professor of Physics, Department of Physics and Engineering Physics, Texas Tech University, Lubbock, Texas

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Professional Record: (continued)

B. Temporary/Past

1945 Premchand, Roychand Studentship; Competitive Award for orginal research from physicists under 32 years of age. Subject: Electron States of Oxides and Halides, Calcutta University.

1947 Mouat Gold Medal; India; Competitive Award for orginal work. Subject: Electronic States for Transition Metals and Alloys.

1950-52 Overseas Fellowship; Gov. of India; Went to the University of Liverpool, England for Ph.D. studies.

1957 Royal Society and Nuffield Federal Bursary; University of Liverpool, England; Investigate Problems of X-Ray Scattering.

1957-59 Fulbright Travel Grant/Sr. Prof. Category; Ohio State University, Columbus, Ohio; Atomic Energy Commission Project on X-Ray Spectroscopy of Reactor Material.

1967-71 Consultant; Massachusetts Institute of Technology, Cambridge, Massachusetts; Space Science Research Center of the Department of Physics, working on Cosmic X-Ray Spectroscopy.

1967 Consultant; U.S. Army Picatinny Arsenal, Dover, New Jersey; Project Study of the Band Structure of Azides by Soft X-Ray Spectroscopy.

1968 Consultant; American Science and Engineering, Cambridge, Massachusetts; Project: X-Ray Instruments for Rockets.

1976-79 Visiting Associate, (without Stipend) Department of Applied Physics, California Institute of Technology, Pasadena, California.

Temporary/Present

1963- Consultant; Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California; Project: Unmanned Space Flight Instrument.

K. Das Gupta
Resume (continued)

Principal Investigator of Research Projects

1967 to Present: Air Force Office of Scientific Research: Compton-Raman Scattering, Search for X-Ray Laser, Stimulated X-Radiation, and Investigations in X-Radiation Stimulation.

1967 to Present: The Robert A. Welch Foundation of Texas: Nature of the Chemical Bond by Soft X-Ray Spectroscopy and Nature of the Chemical Bond by Soft X-Ray Spectroscopy of A_{15} Superconducting Alloys.

Publications

New Radiation Processes--34
Soft X-Ray Spectroscopy--15
Instruments for Precision, X-Ray Diffraction, and Spectroscopy--7
X-Ray Diffraction of Supercooled Liquid, Colloids, and Amorphous Solids--7
Miscellaneous--3

U.S. Patents

(1) Two Curved Crystal Spectrometer and Diffractometer
(2) Focusing Diffractometer

Reviews

(1) Reviewer for AEC and NSF Proposals
(2) Reviewer for Scientific Journals

Some Orginal Findings

(1) Nonlinear Increase in Bragg Peak..., Phys. Letters 46A, 179 (1973).
(2) Non-Divergent Radiation..., Phys. Rev. Letters 33, 1415 (1974).
(3) Diffraction of Discrete X-Ray Frequencies..., J. Appl. Phys. 47, 2765 (1976).

Referred to as Das Gupta's Discoveries and Hypotheses

(1) Compton-Raman lines in x-rays, referred to as Das Gupta' line (verified in other world laboratories). Two papers of Das Gupta's on x-ray scattering have been recommended by the American Association of Physics Teachers for senior and graduate students in Physics (Am. J. Phys. 37, 005 (1969).
(2) A formula to explain binding energy of solids referred to as Das Gupta's Formula of Heat of Formation (Advances in Electronics and Electron Physics VII, 213 (1955).
(3) Coherent crystal radiation (confirmed at Bell Lab, Murray Hill, N.J.)
(4) Fine structures in x-ray lines at Texas Tech with Graduate Students.
(5) Original report on x-ray diffraction of supercooled liquid state.

K. DAS GUPTA

PUBLICATIONS AND WORKS

(A) New Radiation Processes

(B) Soft X-Ray Spectroscopy

(C) Instrument for Precision, X-Ray Diffraction and Spectroscopy
Patents

(D) X-Ray Diffraction of Supercooled Liquids, Colloids, and Amorphous Solids

(E) Miscellaneous Publications

K. DAS GUPTA

Publications and Works

(A) New Radiation Processes

1. A NEW TYPE OF X-RAY SCATTERING
   K. Das Gupta
   Nature 166, 563 (1950).

2. A NEW TYPE OF X-RAY SCATTERING, (Part II)
   K. Das Gupta
   Nature 167, 313 (1951).

3. MODIFIED RADIATION IN X-RAY SCATTERING
   K. Das Gupta
   Science and Culture 21, 542 (1956).

4. ELECTRON TRANSFER TYPE MODIFIED SMEKAL LINES IN X-RAY SCATTERING ON LONG AND SHORT WAVELENGTH SIDE OF THE MONOCHROMATISED INCIDENT X-RAY BEAM
   K. Das Gupta
   Science and Culture 21, 624 (1956).

5. SMEKAL-RAMAN TYPE MODIFIED X-RAY SCATTERING
   K. Das Gupta
   Physical Review Letters 3, 38 (1959).

6. CHARACTERISTIC MODIFIED X-RAY SCATTERING
   K. Das Gupta
   Physical Review Letters 128, 2181 (1962).

7. COMBINATION OF TWO BENT CRYSTAL MONOCHROMATORS FOR PRECISION WORK ON SCATTERING AND DIFFRACTION
   K. Das Gupta
   W.M. Keck Laboratory of Engineering Materials, #20 (1963).

8. A NEW PROCESS OF X-RAY SCATTERING FROM SINGLE CRYSTALS
   K. Das Gupta
   W.M. Keck Laboratory of Engineering Materials, #23 (1964).

9. RECOIL ELECTRON RESONANCE IN CRYSTALS AND THE STOKES AND ANTI-STOKES MODIFIED LINES IN X-RAY SCATTERING
   K. Das Gupta
   Physical Review Letters 13, 338 (1964).

10. RAMAN SCATTERING IN X-RAYS
   K. Das Gupta
   W.M. Keck Laboratory of Engineering Materials, #39 (1966).

(A) New Radiation Processes

11. CRYSTALS AS OPTICAL MIRRORS FOR GAMMA OR X-RADIATION
K. Das Gupta
Bullentin of the American Physical Society, 260 (1966).

12. COMPTON-RAMAN SCATTERING IN X-RAYS
K. Das Gupta
XIII Colloquium Spectroscopicum Internale, Ottawa, 413 (1967).

*13. A RESEARCH PROGRAM ON SOLID PROPELLANT PHYSICAL BEHAVIOR
Paul J. Blatz, K. Das Gupta, and N.W. Tschoegl
California Institute of Technology, Division of Engineering and Applied Science, AFRPL-TR-76-193, (1967).

14. RADIATION AND SOLID STATE RESEARCH
K. Das Gupta
Department of Physics, Texas Tech University (1968).

**15. COHERENT CRYSTAL RADIATION AFFECT THE MEASUREMENT OF THE X-RAY LINEWIDTHS
K. Das Gupta and Herbert Welch
Physical Review Letters 21, 657 (1968).

**16. OBSERVATION OF FINE STRUCTURES OF CHROMIUM $K\alpha_{1,2}$ LINES WITH A HIGH RESOLUTION THREE CRYSTAL SPECTROMETER
M. Shah and K. Das Gupta
Physics Letters 29A, 570 (1969).

17. MODIFIED X-RAY SCATTERING CLOSE TO THE BRAGG SPECTRUM
K. Das Gupta
International Symposium at Kiev, U.S.S.R., 193 (1969).

*18. OBSERVATION OF STRUCTURES IN THE CHROMIUM $K\alpha_1$ LINE WITH SPHERICALLY BENT CRYSTAL SPECTROMETER
K. Das Gupta and P.F. Gott
Physics Letters 33A, 276 (1970).

19. RADIATION LABORATORY FOR BASIC APPLIED RESEARCH
K. Das Gupta
Department of Physics, Texas Tech University (1971).

20. COHERENT INTERACTIONS OF PHOTONS AND ELECTRONS IN CRYSTALS CLOSE TO THE BRAGG ANGLE
K. Das Gupta
Journal De Physique 32, C4-338 (1971).

21. NON-LINEAR INCREASE IN BRAGG PEAK AND NARROWING OF X-RAY LINES
K. Das Gupta
Physics Letters 46A, 179 (1973).

* Colleagues
** Graduate Students

(A) New Radiation Processes

22. EVIDENCE OF STIMULATION IN X-RAY EMISSION
    K. Das Gupta
    Colloquium Spectroscopicum, Internationale XVII, Firenze, Italy ACTA II, 482 (1973).

23. OBSERVATION OF COHERENT CHARACTERISTIC FREQUENCIES IN BREMSSTRAHLUNG
    K. Das Gupta
    IEEE Journal of Quantum Electronics QE-10, 778 (1974).

**24. OBSERVATION OF FINE STRUCTURES IN THE Kα LINES OF 3d TRANSITION ELEMENTS USING A THREE CRYSTAL SPECTROMETER
    S.M. Shah and K. Das Gupta
    Journal of the Physical Society of Japan 37, 1069 (1974).

25. RADIATION LABORATORY BASIC APPLIED RESEARCH
    K. Das Gupta
    Department of Physics, Texas Tech University (1974).

**26. A HIGH RESOLUTION THREE CRYSTAL SPECTROMETER FOR THE USE IN X-RAY EMISSION SPECTROSCOPY
    S.M. Shah and K. Das Gupta
    Japanese Journal of Applied Physics 13, 2042 (1974).

27. NONDIVERGENT RADIATION OF DISCRETE FREQUENCIES IN CONTINUOUS X-RAY SPECTRUM
    K. Das Gupta
    Physical Review Letters 33, 1415 (1974).

28. DIFFRACTION OF DISCRETE X-RAY FREQUENCIES FROM GERMANIUM ATOMS IN CRYSTALS
    K. Das Gupta
    Journal of Applied Physics 47, 2765 (1976).

29. A NEW TYPE OF KOSSEL-BORRMANN RADIATION FROM GERMANIUM CRYSTAL
    K. Das Gupta
    International Conference on the Physics of X-Ray Spectra, Gaithersburg, MD., 260 (1976).

*30. A NONLINEAR RISE IN CHARACTERICTIC X-RAYS FROM GERMANIUM CRYSTALS
    K. Das Gupta and Peter J. Seibt
    Twenty-Sixth Annual Conference on Applications of X-Ray Analysis, University of Denver, Denver, Colorado 104 (1977).

* Colleagues
** Graduate Students

(A) New Radiation Processes

31. GENERATION OF X-RADIATION VIA ELECTRONS IN A CRYSTAL: NONLINEAR RISE AND LINE-NARROWING
K. Das Gupta
PHYSICS OF QUANTUM ELECTRONICS, Vol. V - NOVEL SOURCES OF COHERENT RADIATION, S.F. Jacobs, M. Sargent, and M.O. Scully (Addison-Wesley Publishing Co., Reading, Massachusetts, 1978). p. 381-398.

*32. STUDIES OF THE NONLINEAR RISE IN INTENSITY OF X-RAY LINES
K. Das Gupta, A.A. Bahgat, and Peter J. Seibt
X-Ray Spectroscopy 9, 25 (1980).

33. OBSERVATION OF AN X-RAY BEAM OF 10 MICRORADIAN DIVERGENCE WITHOUT USING ANY COLLIMATOR
K. Das Gupta
Accepted for Publication in ADVANCES IN X-RAY ANALYSIS, Vol. 25, 1982 by Plenum Publishing Corp., New York.

34. NONDIVERGENT MONOCHROMATIC X-RAY BEAMS FROM Ge and GaAs MONOCRYSTALS
K. Das Gupta
Accepted for Publication in Lasers '81 Conference Proceedings by Society for Optical and Quantum Electronics, McLean, Virginia, 1982.

*Colleagues

(B) Soft X-Ray Spectroscopy

1. K-EMISSION SPECTRA OF Si AND C FROM SiC
   K. Das Gupta
   Science and Culture 7, 614 (1942).

2. SOFT X-RAY K-VALENCE BAND SHIFT AND HEAT OF FORMATION OF CHEMICAL COMPOUNDS
   K. Das Gupta
   Science and Culture __, ___ (1946).

3. SOFT X-RAY K-ABSORPTION AND EMISSION EDGE OF ALUMINUM AND SILICON IN MICA
   K. Das Gupta
   Science and Culture 11, 701 (1946).

4. K-EMISSION AND ABSORPTION SPECTRA OF CHLORINE IN CHLORIDES AND THEIR ULTRA-VIOLET ABSORPTION BANDS
   K. Das Gupta
   Science and Culture 11, 702 (1946).

5. SOFT X-RAY K-ABSORPTION AND EMISSION SPECTRA OF Mg, Al, Si, AND THEIR OXIDES
   K. Das Gupta
   Indian Journal of Physics 20, 226 (1946).

6. SECOND ORDER CHLORINE K-VALENCE BAND SPECTRA OF CHLORIDES
   K. Das Gupta
   Indian Journal of Physics 21, 129 (1947).

7. SOFT X-RAY K EMISSION AND ABSORPTION SPECTRA OF SODIUM-HALIDES AND THEIR ULTRA-VIOLET ABSORPTION BANDS
   K. Das Gupta
   Science and Culture 14, 124 (1948).

8. THE SOFT X-RAY VALENCE BAND SPECTRA AND THE HEAT OF FORMATION OF CHEMICAL COMPOUNDS AND ALLOYS
   K. Das Gupta
   Physical Review 80, 281 (1950).

**9. SOFT X-RAY L-SPECTRA OF Fe, Co, Ni, Cu, AND THEIR OXIDES
   K. Das Gupta and S.B. Bhattacherjee
   Indian Jounral of Physics 25, 555 (1951).

**10. SOFT X-RAY SPECTRA OF MAGNESIUM-ALUMINUM, MAGNESIUM-SILICON, AND ALUMINUM-SILICON ALLOYS
   K. Das Gupta and E. Wood
   Philosophical Magazine 46, 77 (1955).

(B) Soft X-Ray Spectroscopy

11. OBSERVATION OF A NEW 3d BAND STRUCTURE OF QUENCHING FERROMAGNETISM
    K. Das Gupta
        Bullentin of the American Physical Society 4, 263 (1959).

12. SOFT X-RAY SPECTROSCOPY OF IRON, COBALT, NICKEL AND SOME ALLOYS AND COMPOUNDS OF IRON
    K. Das Gupta
        W.M. Keck Laboratory of Engineering Materials, #16 (1963).

13. ENERGY LEVEL OF DIAGRAMS OF OXIDES OF MAGNESIUM, ALUMINUM AND SILICON
    K. Das Gupta
        W.M. Keck Laboratory of Engineering Materials, #38 (1965).

14. SOFT X-RAY EMISSION SPECTRA OF AMORPHOUS PALLADIUM-SILICON ALLOY
    K. Das Gupta
        Applied Physics Letters 6, 104 (1965).

*15. X-RAY STUDY OF THE BAND STRUCTURE IN STANNIC OXIDE
    A.A. Bahgat and K. Das Gupta
        ADVANCES IN X-RAY ANALYSIS, Edited by John R. Rhodes et al., (Plenum Publishing Corporation, New York, N.Y. 1980). p. 203-207.

* Colleagues
** Graduate Students

(C) Instruments For Precision, X-Ray Diffraction, and Spectroscopy

**1. STUDY OF CARBON Kα AND ALUMINIUM $L_{2,3}$ BANDS BY A NEWLY CONSTRUCTED SOFT X-RAY RULED GRATING SPECTROGRAPH
K. Das Gupta, A.K. Sen, and S.B. Bhattacharjee
Journal of Scientific and Industrial Research 14B, 129 (1955).

**2. A NEW BENT CRYSTAL SOFT X-RAY VACUUM SPECTROGRAPH
B. Mitra and K. Das Gupta
Journal of Scientific and Industrial Research 16B, 524 (1957).

**3. A NEW EXPERIMENTAL TECHNIQUE FOR X-RAY DIFFRACTION STUDY
K. Das Gupta and N. Pan
Journal of Scientific and Industrial Research 17B, 131 (1958).

4. CONICAL TWO CRYSTAL MONOCHROMATOR FOR SCATTERING, DIFFRACTION, AND ABSORPTION CROSS SECTION WORK WITH SLOW NEUTRONS
K. Das Gupta
The Review of Scientific Instruments 32, 602 (1961).

*5. A COMBINED FOCUSING X-RAY DIFFRACTOMETER AND NONDISPERSIVE X-RAY SPECTROMETER FOR LUNAR AND PLANETARY ANALYSIS
K. Das Gupta, Herbert W. Schnopper, Albert E. Metzger, and Rex A. Shields
ADVANCES IN X-RAY ANALYSIS, Vol. 9, (Plenum Press, New York, N.Y., 1966) p. 221-241.

***6. SOME NEW METHODS OF PRECISION X-RAY SPECTROMETRY
K. Das Gupta, P.F. Gott, Herbert Welch, John F. Priest, Sunny Cheng, and Edmond Chu
ADVANCES IN X-RAY ANALYSIS, Vol. 16, (Plenum Publishing Corp. New York, N.Y., 1972) p. 251-259.

*7. A NEW TYPE OF X-RAY ABSORPTION SPECTROMETER
A.A. Bahgat and K. Das Gupta
The Review of Scientific Instruments 50(8), 1020 (1979).

* Colleagues
** Graduate Students

PATENTS

1. PATENT 3,379,876, X-RAY DIFFRACTION CAMERA EMPLOYING TWO CURVED CRYSTAL TRANSMISSION TYPE MONOCHROMATORS
   K. Das Gupta
   United States Patent Office, April 23 (1968).

*2. PATENT 3,440,419, DUAL PURPOSE OPTICAL INSTRUMENT CAPABLE OF SIMULTANEOUSLY ACTING AS SPECTROMETER AND DIFFRACTOMETER
   K. Das Gupta, Herbert W. Schnopper, and Albert E. Metzger
   United States Patent Office, April 22 (1969).

3. NONDIVERGENT X-RAYS OF DISCRETE FREQUENCIES EMITTED PARALLEL TO THE TARGET SURFACE (PATENT APPLIED)
   K. Das Gupta
   (1974).

* Colleagues

(D) X-Ray Diffraction of Supercooled Liquids, Colloids, and Amorphour Solids

*1. CONVERSION OF VITREOUS AND MONOCLINIC (α) SELENIUM TO THE HEXAGONAL MODIFICATION
S.R Das and K. Das Gupta
Nature 143, 165 (1939).

*2. X-RAY DIFFRACTION OF SUPERCOOLED LIQUID SULPHUR
S.R. Das and K. Das Gupta
Nature 143, 332 (1939).

3. DEVITRIFICATION OF VITREOUS SELENIUM AT VARIOUS TEMPERATURES, AND THE CONVERSION OF THE MONOCLINIC (α) Se INTO HEXAGONAL MODIFICATION
K. Das Gupta
Science and Culture 5, 636 (1940).

4. THE PRESENCE OF Sω IN COLLOIDAL SULPHUR
K. Das Gupta
Science and Culture 5, 638 (1940).

*5. A STUDY OF ALLOTROPES OF SELENIUM BY THE X-RAY DIFFRACTION METHOD
K. Das Gupta, S.R. Das, and B.B. Ray
Indian Journal of Physics 15, 389 (1941).

*6. X-RAY STUDY OF SELENIUM IN THE LIQUID AND COLLOIDAL STATE
K. Das Gupta and S.R. Das
Indian Journal of Physics 14, 401 (1941).

7. STUDY OF SMALL ANGLE X-RAY SCATTERING USING TWO CURVED CRYSTALS IN CAUCHOIS GEOMETRY
K. Das Gupta
Program and Abstracts of the Fifth International Conference on Small Angle Scattering SMAS, Berlin (West), Germany, October 1980, p. 50.

* Colleagues
** Graduate Students

(E) Miscellaneous Publications

*1. THE FLUORESCENCE OF ORGANIC COMPOUNDS BY X-RAYS
H.N. Bose and K. Das Gupta
Science and Culture 5, 497 (1940).

*2. THE FLUORESCENCE OF ORGANIC COMPOUNDS BY X-RAYS, (PART II)
H.N. Bose and K. Das Gupta
Science and Culture 5, 569 (1940).

3. E.M.F. DUE TO DIFFERENCE IN TEMPERATURE BETWEEN TWO ELECTRODES DIPPED INTO IONIC SOLUTIONS
K. Das Gupta
Science and Culture 9, 563 (1944).

* Colleague